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Pitch Control of Variable Speed Wind Turbine Through PI Controller

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Abstract: Recently, due to energy shortages and environmental concerns, considerable attention has been paid to renewable energy, especially wind energy. As the penetration of wind energy into the electrical power grid is increased significantly, the effect of wind turbine systems on frequency and voltage stability is becoming ever more important. Pitch angle control is typically used to control the wind energy system's output torque if wind speed reaches base speed, and other variables such as wind speed, generator speed, and generator power can also be chosen for control. In this paper a pitch control scheme is proposed which is based on a PI controller design. Comparative analysis of the proposed strategy with that of already existing ones shows that it gives an overall better result than those prevalent techniques.

Keywords: PI controller; Wind turbine; Speed control; Generator power; Pitch angle.

1. Introduction

A prominent rise in the use of high-power electrical mechanisms has been observed with continuing growth in field of IT and science, and nearly the world appears to be totally turned on the use of electrical machines, that will rise the demand for electrical power and yes, electricity can be generated implementing distinct methods, or generally speaking, there are renewable and non-renewable power resources in Pakistan but, considering the environmental concerns, many of non-renewable resources are hazardous for environment due to specific emissions. Therefore, renewable power resources are the chief focus/concern for scientists for the enhancement of electricity generation. Wind and Solar are two chief renewable power sources. Extensive research is being done on solar mechanisms, but wind power generation mechanisms need to be worked on and many problems need to be resolved in this region. That's the reason for my wind power mechanisms studies. Wind power is a power source that is sustainable and environmentally friendly. In many nations, a steady growth has been observed in area of generation of power by use of wind to address climate change and global warming issues. Among the complete capacity installed, a rising figure of big wind generators are starting to install o shore to exploit the abundant o shore wind resources (Ahlgrimm, 2016). Even so, reliable wind generator operation is the main factor in cost-effective shore wind power harvesting and, in particular, maintenance and repair operations are becoming expensive for shore wind generators situated in a distant region. Therefore, there are certain techniques that can decrease expensive upkeep and repair processes. One of them is practice of air-blade pitch control as a way of lessening the detrimental concrete generator loads resulting from spatially uneven and temporarily unsteady blowing wind. Load mitigation on the core generator parts boost's operational reliability, as well as it also leads to a substantial drop in the price of the needed products. Henceforth, this exploratory study encourages the wind generator load reduction air-blade-pitch control strategies.

2. Literature Review

The wind power generated by generators can possibly be upgraded by employing following of two control strategies, those strategies are: pitch control and stall control. The main and common step in both control mechanism is the use of electronic controller to check the output of power generated by the generator numerous times per second.

Whenever the wind speed is over the working constraints, rotor air-blades spin out of the wind slightly because of an indicator is propelled to the air-blade pitch mechanism that adjusts the angle of attack. Those air-blades are transformed back into the wind once the wind cascades. Generators with such mechanism of control are known as wind generators regulated by pitch.

Many of researchers has used the arrangement of P, I and D for the adjustment of generator rotor velocity to generate peak power without any estimation of speed of wind [1,2,3]. In stall control method, the rotor air-blades are attached to the hub at a fixed angle in the stall control technique. The geometry of rotor air-blade is intentionally structured aerodynamically to ensure the creation of turbulence on the back rotor air-blades from the moment the wind speed to become it too big, leading to the air-blade stall [2].

Control is used to regulate the WT in a fluid-based, where peak yields are acquired through particle swarm optimization and fluid logic theory, devoid of estimation of the wind speed [4]. Fuzzy logic control techniques are again employed to progress the pitch control of gauze-connected wind generators [5,6]. Feedforward Learning Control of Modern Two-Air-bladed Wind Generators for Individual Air-blade Pitch Control is explained in the study [7]. Researchers are exploring another strategy to control big wind generators by multivariable design [8]. This multivariable design method is helpful to regulate the output power at variable velocity simultaneously to regulate the tip speed ratio and thus the power extricated for distinct wind speeds [8].

An arrangement of fuzzy and PID controllers for controlling WT at the above-mentioned temperature speeds was discussed by the authors [9]. However, this article uses PID control, fuzzy control as well as adaptive fuzzy PID for wind generator mechanism pitch control. However, a frequent fluctuation occurs in the output power of wind generators in curs due to the casualness of the wind speed and course, hence affecting the quality and stability of the electrical power network. So how to ensure the unwavering quality and wellbeing of the activity of the power mechanism and how to upgrade the quality and viability of the age of vitality has become a noteworthy theme of concentrates in the wind control framework. Fixed pitch wind generators' air blades are fixed on the routers, making the steep angle irregular when the speed of wind is greater than that of the rated wind. Fixed pitch wind generators have high wind speeds, high impact pressure when they stop, and so on, which is why variable pitch wind generators appear at this historic time. The steep angle of the variable pitch wind generators can be calibrated in conjunction with the wind speed, the steep angle can be improved to reduce the windward region. Also suggested was a wind generator model with generator protection controller at elevated wind speed. The model of the PMSG and the converter was created. This model controller was able to keep a steady output capacity when the speed varied over a 4-25m / sec range. It also led in a reduction of the mechanical stresses in the generator and a reliable output capacity.

One disadvantage of these standard PID controllers is that they are not well adapted to compensate for the disruptive impacts of the wind generation scheme. A control mechanism is needed to compensate for scheme non-linearity and altering parameters. Today, the perfect control technique to solve the drawbacks is the fuzzy control that holds a significant position in contemporary control theory. One of the biggest benefits of fuzzy controller to traditional control methods; it doesn't need to understand the object's mathematical model that wants to be controlled. In [10] Z. Implementing a blurred controller, Civelek, Murat Lüy, ErtuğrulÇam, GöksuGörel submitted research on the steep angle control of wind generator air-blades. Within certain boundaries, the output power was retained at a steady value. In addition, the generator has been protected from the upper limit on the rated output power, it can task securely for a longer period of time as well as providing more stable power yielded to the gauze. The Fuzzy controller has a nice adaptation to modifications in the scheme and it can also compensate for problems in controlling that according to the nonlinear mechanism. But the powerful nonlinear and big moment of wind generator inertia leads to the complexity of variable pitch control, no excellent control impact can be achieved by both easy fuzzy control and standard PID control. F. Zhang, Y. Lu, F. Qiao and C. Bai [11] used the selftuning Fuzzy adaptive PID control approach in VSCF wind power mechanism variable pitch control, the PID controller parameters are calibrated online by implementing Fuzzy control laws for distinct errors and error rates. The suggested controller has excellent dynamic efficiency, powerful robustness and adaptability capability, and the angle of pitch can be efficiently controlled, and excellent control impact can be accomplished. In 2017, Dr. A. Ismail in [12] S. Borjaan adopts non-linear features of the wind generator as well as a fresh steep angle control method based on fuzzy logic control to reduce the load on air blades. A calculated framework of wind generator (pitch control mechanism) was created and tested with three controllers PID, fuzzy and adaptive fuzzy PID. Contrasting the three scheduled methods, it was exhibited that adaptive fuzzy PID controller is more responsive because it also controls the pitch mechanism. The objective of this job, based on the literature study carried out, is to propose controller design that can overcome the drawbacks of the earlier suggested controller by efficiently keeping the output power at its rated value. If have time will try to implement in my research or will be kept for future works.

3. Proposed Methodology

3.1 Modelling of the Proposed Wind Turbine

To generate cheapest electrical power Wind generators have been equipped. During periods of strong winds while avoiding wind generator damage, it is important to eliminate some of the excess wind. As a result, all wind generators are equipped with some kind of power control. To control the wind speed two different control mechanism can be used. One is the steep angle control, and the other is the stall control.

When the speed becomes less than or greater than the rated speed, it results in non-linarites and rise and decrease in the rated output power. Sometimes the speed greater than the rated speed may result in complementing damage at the load. Therefore, a controlling mechanism is needed so sustain the output power to the rated value.

Figure 1 is a generalized block diagram that exhibits how the wind generator that has a control mechanism works. When the wind collides with a wind generator, it converts the kinetic power of the wind into mechanical power that drives the train, which is then transformed to electrical power implementing a wind turbine generator. Finally, this electrical power is given to the power gauze. The controller here measures the generator speed and adjusts it if it is higher than the rated speed.

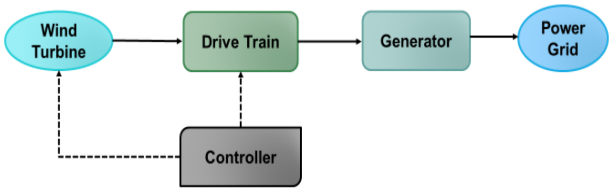

Figure 1. Generalized block diagram of a wind energy system

3.2 Proposed Model

The proposed methodology is shown in the black diagram as shown in Figure 2.

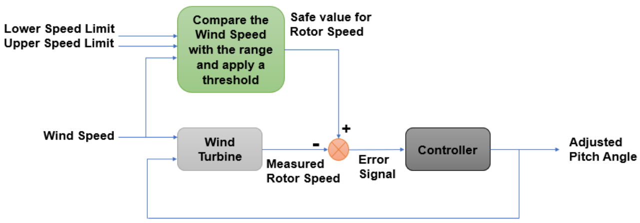

Figure 2. Flow chart of the proposed methodology

Here we have the wind turbine block which has two inputs, the wind speed, and the pitch angle. The output of the wind turbine is the rotor speed which is then compared with the reference speed which is obtained by protection system. In the protection system, basically comparing the wind speed with the specified range of wind speed at which turbine can operate safely. The output of this switching control is the reference rotor speed which is then given to the summer for calculating the error. The error signal is the difference of the reference and the measured rotor speed. This error signal is then given to the PI controller. Finally, the controller minimizes the error signal as much as possible by adjusting the pitch angle value. This adjusted pitch angle value is then given to the turbine through a feedback path.

3.3 Controller Design

One of the main benefits of a PID controller is that it can be used with a higher order process that stores more than one power. (P), integration (I) and difference (D), which will produce the monitored target (T)output. Fig. 3 [13] illustrates the principles. The performance of a PID controller in the time domain is given in Equation 1.

$$u(t) = K_P e(t) + K_I \int e(t)\, dt + K_P \frac{de}{dt} \quad (1)$$

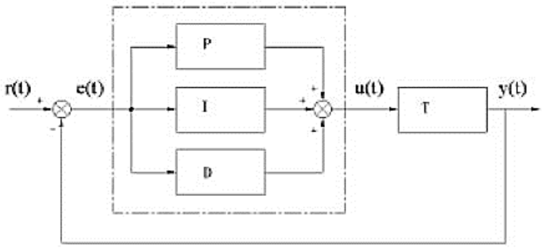

Figure 3. Principal diagram of PID controller

Now, look at how the PID controller tasks in a closed-loop mechanism implementing the following the schematic [14] shown in Figure 4.

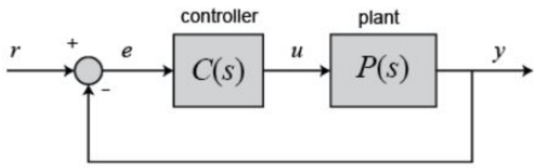

Figure 4. Unity Feedback System

3.4 Methods for Tuning the Gains of Controller

Root locus are a visual representation of closed loop poles because the mechanism parameter is wide. It can be used to dynamically describe the output of a mechanism as different parameters have been modified. We can see instability and instances that cause instability of a mechanism.

From open loop pole(K=0) to open loop zero (K = Infinity) the root locus begins. The main advantage of root locus is to check the behavior of the mechanism by adjusting the gain value K[15-19]. The change in the value of K will trace the roots on the RH plane accordingly and will yield the conditions for overdamping, underdamping, critically damping, overdamping or undamping of the device according to the respective value of k. If :

- Roots are same and real - critically damped mechanism.
- Roots are real and distinct- overdamped.
- Roots are purely imaginary- marginal stable mechanism.
- Roots are complex conjugate pairs- underdamped.
- It also yields the K limit to change until the mechanism becomes unsteady.

One major drawback of the RL technique is that it cannot measure stability, i.e., it always shows whether the mechanism is more or less stable as k->infinity, or for a particular k. It's not saying precisely how much or offering any meaning for quantitative analysis. It's a linear process for the most part. In a nonlinear method, may or may not perform well. In no way does the approach take care of optimization. It works well on mechanisms defined by testing the time domain.

Ziegler-Nichol's rule is a Pure tuning principle that seeks to produce good values for the three parameters of obtaining a PID.

- Get the KP-Controller Path
- T - Controller Integrator Time constant
- TD - Controller derivative time constant
- Given two measured parameters of the feedback loop that are derived from measurements:
- The period Tu of the oscillation frequency at the stability limit

- The gain margin Ku for loop stability

The benefit of the Ziegler-Nichols approach is that it is very straightforward to use the tuning rules. It is easy to use and quicker than other approaches. It's a strong and popular mechanism. Drawbacks are:

- We need more fine tuning. Controller settings are violentleading to broad over-shooting and oscillating responses. Poor performance for primarily delayed processes.
- Estimating I and Dcontrollers relies on strictly proportional calculation.
- For various mechanisms, approximations for the Kc, Ti, and Td values may not be entirely accurate.
- For I, D and PD controllers, it does not hold.

Trial and error procedures require a closed loop mechanism, from proportional to conscience as it flows through the device. This strategy is a divisive and trivial technique before which the mechanism is somehow integrated into a solution where tweaks are performed to complete the response. To start, each PID controller capability is set to zero. By increasing its value, the proportional variable is now considered until a stable mismatch is found in Figure 5, which will result in the proportional value being scaled by the current proportional value. Stable duplicates will be discarded by adding a proportional value. Next, the coefficient of integration is raised until there is stable duplication. The current value of the integral multiplier is multiplied by a factor of three and included in the integration as the final value. This again eliminates the two drugs, which in turn produces derivative strength; its value is raised until the continuum is at a constant duration and a final time dimension. The derivative numbers are then subtracted by a factor of three and added to the derivative control as the final value. As a result, there may still be some noise associated with it, now it should be made by hand with a slight awareness of the various abilities [20-25].

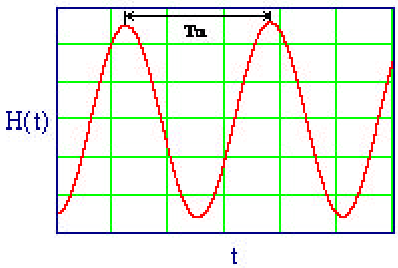

Figure 5. Steady Oscillation representing the Optimum Period

Hit and test approach is used in the scheduled work. Thanks to the insight and clarification, it offers with what the PID components are doing, the trial-and-error approach is very popular not only in educational settings. Sometimes, after implementing a method such as the root locus or Ziegler-Nichols, some manual tuning is desirable to get the device calibrated specifically for the mechanism in hand, whether it is more robust to handle large disruptions or keenly responsive to respond instantly to the mechanism's small annoyances [26-28].

4. Simulation Model

The simulation of the proposed model has been carried out on MATLAB 2013/Simulink. The Simulink model of the proposed wind energy system along with the controller is shown in Fig. 6. The range of wind speed is taken from 8ms-1 to 25ms-1. The reference speed is taken to be 2.5rad/s (or 23.87 rev/min). The gains of the controller are set using the hit and trial method.

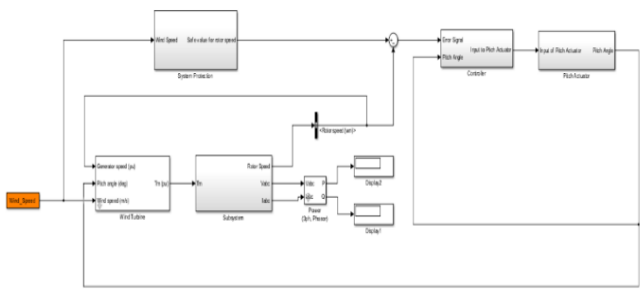

Figure 6. Simulation Model for the Proposed Wind Energy System

4.1 Simulation results

In this section, the results obtained by the designed controller are discussed, when it is connected with the wind energy system. The reference speed is taken to be 2.5 rads-1.

4.2 Rotor Speed Graph

Figure 7 shows the variation of rotor speed with different wind speed. From these graphs it can be concluded that for any value of wind speed, the rotor speed gets stable at the same point. Basically, as the wind speed increases, the rotor speed tends to increase but the controller stabilizes it to a certain point for all the wind speed.

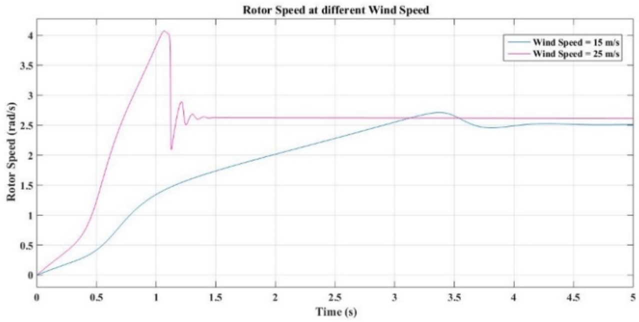

Figure 7. Rotor Speed at Different Wind Speed

4.3 Pitch Angle

Figure 8 shows the graph of blade pitch angle of the wind turbine at different wind speeds. The wind speed values are taken to be 8ms-1, 10ms-1, 15ms-1 and 25ms-1. The graph illustrates that with the increase in wind speed, the controller tends to decrease the blade pitch angle so as to avoid the blades of the turbine to bear stress caused by high wind speeds.

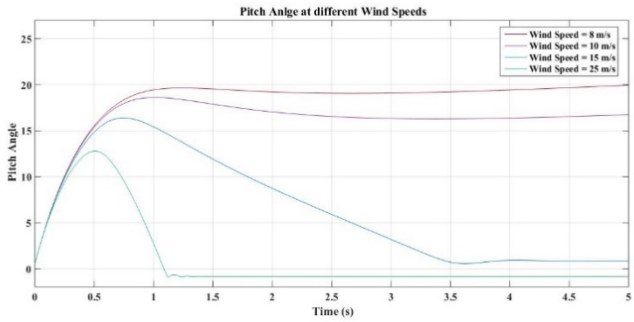

Figure 8. Pitch Angel at Different Wind Speed

4.4 System Protection

Fig. 9 shows the graphs for system protection. As long as the turbine operates at the wind speed within the specified range, the turbine operates normally. However, when the wind speed falls below the rated speed or exceeds the rated speed, the controller decreases the rotor speed to a value that almost stops the turbine, thus protecting it from any possible damages that may occur at very high or very low wind speeds.

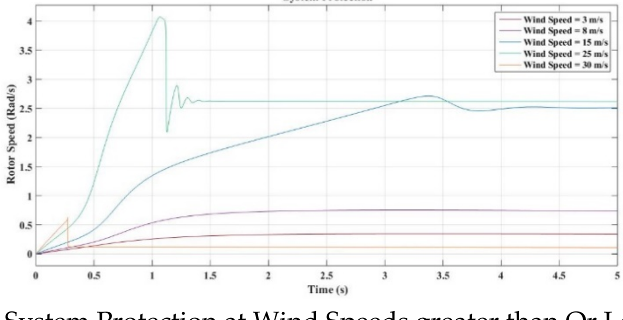

Figure 9. System Protection at Wind Speeds greater than Or Less than the Rated Speed

4.5 System Voltages

As the wind speed increases, the system voltage tend to increase. This is illustrated in Fig. 10 to Fig. 14 at rated speeds 0.5 rads-1, 1.87 rads-1 and 2.5 rads-1 respectively.

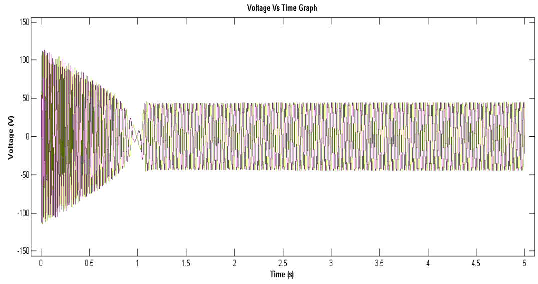

Figure 10. System Voltage at Wind Speed at 0.5 rads^{-1}

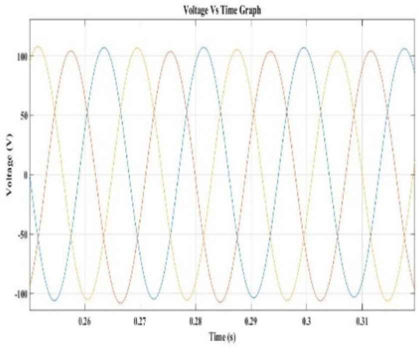

Figure 11. Zoomed in Portion of System Voltage at Wind Speed=0.5 rad^{-1}

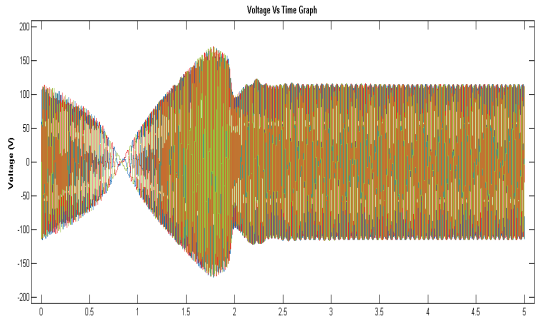

Figure 12. System Voltage at Wind Speed=1.87 rad^{-1}

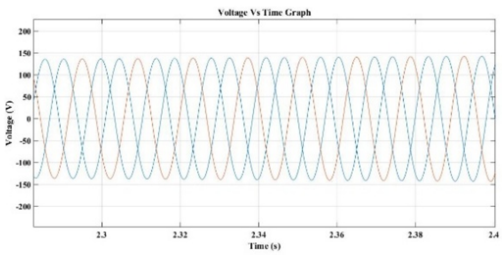

Figure 13. Zoomed in Portion of System Voltage at Wind Speed=1.87 rad^{-1}

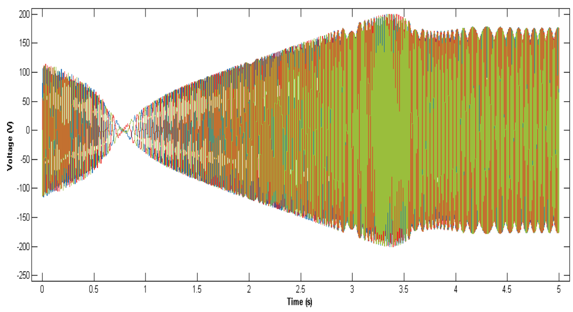

Figure 14. System Voltage at Wind Speed=2.5 rad^{-1}

4.6 Controller Error Signal

The controller error signal of the system is shown in Fig. 16

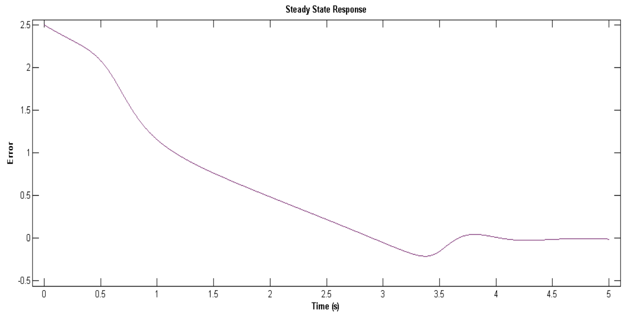

Figure 15. Controller Error Signal

4.7 Power at Different Speeds

Comparison of output power at two different wind speeds i.e. 15 ms-1 and 25 ms-1 is shown in Fig. 17. It can be observed that output power tends to increase with wind speed rise but the controller tends to control the power as well by adjusting the pitch angle and keeps the power stable at the rated value.

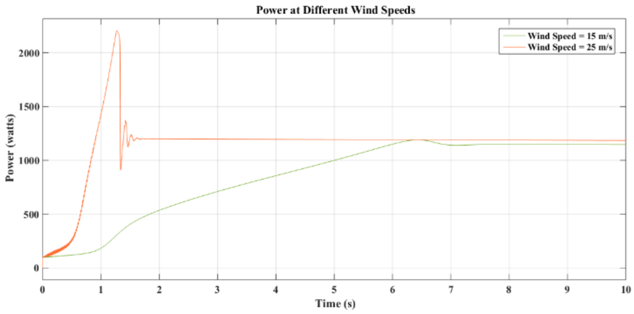

Figure 16. Power at Different Wind Speeds

5. Conclusions

To generate cheapest electrical power Wind generators have been equipped. To avoid strong wind periods, it is necessary to waste some part of the extra air while the duration of strong winds. As a result, all wind generators are equipped with some kind of power control. A PI controller is equipped to adjust the steep angle of the wind generator's air blade in such a way that it can perform normal operation even in high wind conditions. It will shield the generators from any damage that could be caused by changes in the speed of wind.

By changing the steep angle, we are principally altering the orientation of the air-blades of the generators of the wind. Doing so causes the air blades to be slightly out of the air, thus reducing the angle of attack. Later when the wind speed decreases, the generator wind driven air is diverted again. It has been identified as pitch control of wind generators.

In future, this work can be extended by implementing fuzzy rules to tune the parameters of PI controller. Further, the PI controller can be extended to PID to get more efficient and preferable results.

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